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TECHNICAL MANUAL FOR MPL-60 MODEL 10,000 SIX CHANNEL HIGH PASS/--ETC(U)
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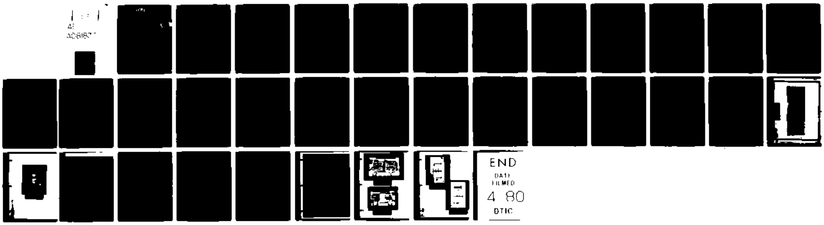

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MPL TECHNICAL MEMORANDUM 243

Technical Manual for MPL-60 Model 10,000 Six Channel High Pass / Low Pass Filter

by

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MPL-TM-243, MPL-U-25/73

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SECTION I
GENERAL INFORMATION

1-1 DESCRIPTION

The MPL 60 Model 10,000 filter ~~shown in Figure 1~~ is a six-channel integrated circuit electronic filter, adjustable over a frequency range from 1 Hz to 90 kHz. The passband gain is selectable, 0 or 20 db except in the x 10 kHz high pass mode. The filters are selectable high pass (HP) or low pass (LP), second order maximally flat Butterworth providing a skirt rolloff of 12 db per octave.

The filters exhibit a high input impedance and a low output impedance with special output decoupling to handle highly capacitive loads without instability. The ten selectable break frequencies are evenly distributed along a one decade log-frequency scale.

1-2 SPECIFICATIONS

Frequency range:

BAND	MULTIPLIER	FREQUENCY (Hz)
1	x 1	1, 1.5, 2, 2.5, 3, 3.5, 4, 5, 6, 7, 9
2	x 10	10, 15, 20, 25, 30, 35, 40, 50, 60, 70, 90
3	x 100	100, 150, 200, 250, etc.
4	x 1 K	
5	x 10 K	

Cutoff Frequency Calibration:

$^{+2}_{-10}$ % for bands 1 through 4, 50 % tile of -5.5%, ±12% for band 5.

Bandwidth:

Low pass mode: dc to cutoff frequency set with range switch.

High pass mode: from selected cutoff frequency to upper -3 db point at approximately 350 kHz for a gain of x 1 (250 kHz for the x 10 K HP mode), - 3 db point with a gain of x 10 is 48 kHz.

NOTE: due to gain bandwidth limits in the 10 kHz HP band in frequency calibrations cannot be relied upon.

Stopband Attenuation:

Better than 85 db.

Insertion Loss:

Zero ±0.5 db to 150 kHz in x 1 gain position. 3.5 db in x 10 K HP mode to 150 kHz.

Input Characteristics:

Impedance: 1.0 megohm in parallel with 10 pf.

Absolute maximum input: 10 vrms with no dc component.

Maximum dc component: combined ac plus dc must not exceed 14 volts pk.

Low pass mode: -60 ±30 mv dc offset with input shorted and in x 10 gain position. Dc offset is a function of frequency selector setting, worse case is at 1 Hz with the least amount of offset occurring at 9 Hz. A -5 volts offset occurs with input open circuited in x 10 gain position.

High pass mode: same as low pass mode except no change with input open circuited.

Output Characteristics:

Output impedance: 18 ohms

Maximum voltage: 8.5 vrms (saturation level)

Maximum slew rate: 35 v/microsecond

Maximum output current: 7 Ma

Noise, 60 and 120 Hz pickup:

Electronic noise is less than -140 dbv as measured in a 1 Hz band inside the filter passband at 10 kHz in the x 10 gain position. 60 Hz pickup is $-77\,^{+15}_{-8}$ dbv and 120 Hz pickup is $-74\,^{+8}_{-3}$ dbv as measured at the output in the x 10 gain position. The channels with the highest pickup are 1 and 2 next to the power switch.

Operating Temperature Range:

0° to 70°C.

Power Requirements:

115 ±10 vac, 50 to 450 Hz, 45 watts.

Dimensions and Weight:

7 inches high x 19 inches wide (rack mountable) x 4-1/2 inches deep

Net weight 7-1/2 lbs.

SECTION II
OPERATION

2-1 LOCATION OF CONTROLS

The location of the front panel controls is shown in the photo of Figure 2.

1. Input: input connector (BNC)
2. Filter: switches between high pass and low pass filter mode
3. Frequency: selects the filter break frequency in Hz
4. Multiplier: the product of the multiplier setting and the frequency setting determine the filter break (-3 db) frequency.
   NOTE: in 10 K position in high pass mode the filter has a 3.5 db of insertion loss.
5. Gain: sets filter passband gain at either x 1 (0 db) or x 10 (20 db).
   NOTE: Do not use x 10 gain with multiplier on x 10 K position.
6. Output: output connector (BNC)
7. Power Switch
8. Power pilot lamp

SECTION III
THEORY OF OPERATION

3-1 GENERAL

The basic filter is illustrated in the HP/LP filter simplified schematic of Figure 3. The filter is composed of two basic stages, a noninverting preamplifier in front of a switchable active filter. The preamplifier acts as either a voltage follower or a 20 db noninverting gain stage. The two pole active filter design is unique in that it uses the same components for the high pass mode as it does for the low pass mode. In the operation of the filter the "Multiplier" switch changes the values of C1 and C2 and the "Frequency" switch controls the resisters R1 and R2 as shown in the simplified schematic.

Typical high and low pass frequency response curves for the filter are shown in Figure 4. These curves have been normalized to 1.0 Hz in order to determine the response at any other frequency.

3-2 SCHEMATIC DESCRIPTION (see Figure 5)

Referring to the complete HP/LP filter schematic, the signal input is applied to the noninverting input of the 531 operational amplifier IC1. R3 provides a dc return for the noninverting input and establishes the input impedance. With S1 in the x 1 position IC1 is in a voltage follower configuration. In the x 10 position it is in the noninverting gain configuration with the gain being determined by $A = (R4 + R5)/R4 = 10.018$.

The 100 pf capacitor between pin 8 and 6 of IC1 sets the open loop gain and phase response and provides an adequate gain and phase margin for stability. For more details on this see the operational amplifier data sheet in appendix A.

Supply isolation between separate filters is provided by the RC networks made up by R1, R2, C1, and C2 which combined with the unity gain voltage

follower IC2 make up the active filter. For the switch positions shown in Figure 5, the filter is in the high pass mode.

The HP/LP filter synthesis process is carried out in appendix C and a basic filter design program is presented in appendix D.

Added high frequency stability is achieved in the output stage by adding R6 inside the feedback loop for the voltage follower IC2. R6 and R7 both act to isolate highly capacitive loads from the operational amplifier, thereby preventing open loop phase modification which could result in instability.

3-3 HIGH FREQUENCY PERFORMANCE

The upper frequency limit of the HP/LP filter set is determined by the open loop gain characteristics of the two operational amplifiers used. The high frequency rolloff characteristics of the filter are shown in Figure 6 for both gain positions. A significant bandwidth limitation takes place in the x 10 gain position as compared to the x 1 position. It should be pointed out that this plot is only characteristic of the high frequency response of the filter, variations will take place from one filter to another due to variations in the operational amplifiers used.

Stray wiring capacitance affects the high pass response of the filter in the x 10 kHz Multiplier position resulting in a 3.5 to 4.0 db passband insertion loss as illustrated in the frequency response plot of Figure 7. Because of the combined effects of the amplifier gain-bandwidth limitation and the stray capacitance, the x 10 kHz frequency band should not be used with 20 db of gain (i.e., x 10 gain).

SECTION IV
MAINTENANCE

In the event of a filter failure the first things to check are the power-line fuses located on the rear of the chassis. Only replace with a 3/8 AMP MDL fuse. If the fuses are good, the next thing to check should be the power supply output voltages. They can be checked at one of the filter PC boards as shown in Figure 8. If one or both of the supply voltages are low or completely down, the following problems may exist: (1) If low, this may indicate a loading effect on the supply, or a faulty supply; this can be checked by unsoldering the dc leads from the supply and measuring the supply voltage. (2) If one or both of the supply voltages are completely zero, then either a direct short exists or there is an open circuit between the PC board and the supply. If the supplies are at their correct ± 15 volt levels then signal tracing is in order. With a signal applied to the input proceed to trace it through to the output using points on the filter PC board as test points, refer to Figure 8.

Component locations on the filter printed circuit cord are indicated in Figure 9. Figures 10a and 10b show the location of the switches and some of the switch components.

SECTION V

REPLACEMENT PARTS

SYMBOL	DESCRIPTION				MFR	PART NO.
R1A	Metal film resistor	102 K	1%	1/8 W	CGW	RN5501023F
B		68.1 K				
C		51.1 K				
D		41.2 K				
E		34.0 K				
F		29.4 K				
G		25.5 K				
H		20.5 K				
I		16.9 K				
J		14.3 K				
K		11.3 K				
R2A		243 K				
B		162 K				
C		124 K				
D		97.6 K				
E		80.6 K				
F		69.8 K				
G		60.4 K				
H		48.7 K				
I		40.2 K				
J		34.8 K				
K		27.4 K				
R3	Carbon resistor	1,000,000 Ω	5%	1/8 W		
R4	Metal film resistor	4,900 Ω	1%	1/8 W	CGW	RN5504991F
R5	Metal film resistor	45,000 Ω	1%	1/8 W		

SYMBOL	DESCRIPTION			MFR	PART NO.
R6	Carbon resistor	200	5% 1/8 W		
R7	Carbon resistor	18	5% 1/8 W		
R8	Carbon resistor	22	5% 1/8 W		
R9	Carbon resistor	22	5% 1/8 W		
R10	Carbon resistor	22	5% 1/8 W		
R11	Carbon resistor	22	5% 1/8 W		

SYMBOL		DESCRIPTION				MFR	PART NO.
C1	A	Mylar Capacitor	1.5 MFD + 20%		200 V	EC	EZ10B1C155M
	B	Mylar Capacitor	0.15 MFD			EP	ZD2A154K
	C	Silver Mica	.015 MFD	±5%	500 V		CM07FD153J03
	D	Silver Mica	1500 PF		500 V		CM06FD152J03
	E	Silver Mica	100 PF		500 V		CM15ED101J03
C2	A	Silver Mica	0.68 MFD	±10%	100 V		
	B	Silver Mica	.068 MFD	±10%	100 V		
	C	Silver Mica	6800 PF	±5%			
	D	Silver Mica	680 PF	±5%			
	E	Silver Mica	43 PF			EM	
C3		Disc Ceramic Capacitor	100 PF	10%	1 KV		
C4		Disc Ceramic Capacitor	100 PF	10%	1 KV		
C5		Disc Ceramic Capacitor	.01 MFD		1 KV		Z5U
C6		Disc Ceramic Capacitor	.01 MFD		1 KV		Z5U
C7		Disc Ceramic Capacitor	.01 MFD		1 KV		Z5U
C8		Disc Ceramic Capacitor	.01 MFD		1 KV		Z5U
IC1		Operational Amplifier	NE 531 (see data sheet in appendix)			SIG	
IC2		Operational Amplifier	NE 531 (see data sheet in appendix)			SIG	
S1							
S2							
S3							
S4							
F1,2							

SECTION VI
APPENDIX

A. Signetics 531 Operational Amplifier Specification Sheet

B. Power Supply Specification Sheet

C. HP/LP Filter Design Data

D. Basic Computer Design Program

APPENDIX A

HIGH SLEW RATE OPERATIONAL AMPLIFIER 531

LINEAR INTEGRATED CIRCUITS

DESCRIPTION

The 531 is a fast slewing high performance operational amplifier which retains D.C. performance equal to the best general purpose types while providing far superior large signal A.C. performance. A unique input stage design allows the amplifier to have a large signal response nearly identical to its small signal response. The amplifier can be compensated for truly negligible overshoot with a single capacitor. In applications where fast settling and superior large signal bandwidths are required, the amplifier out performs conventional designs which have much better small signal response. Also, because the small signal response is not extended, no special precautions need be taken with circuit board layout to achieve stability. The high gain, simple compensation and excellent stability of this amplifier allow its use in a wide variety of instrumentation applications.

FEATURES

- 35V/µsec SLEW RATE AT UNITY GAIN
- PIN FOR PIN REPLACEMENT FOR µA709, µA748 OR LM101
- COMPENSATED WITH A SINGLE CAPACITOR
- SAME LOW DRIFT OFFSET NULL CIRCUITRY AS µA741
- SMALL SIGNAL BANDWIDTH 1 MHz
- LARGE SIGNAL BANDWIDTH 500KHz
- TRUE OP AMP D.C. CHARACTERISTICS MAKE THE 531 THE IDEAL ANSWER TO ALL SLEW RATE LIMITED OPERATIONAL AMPLIFIER APPLICATIONS.

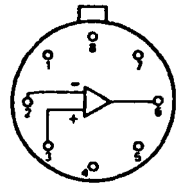
ABSOLUTE MAXIMUM RATINGS

Supply Voltage	±22V
Internal Power Dissipation (Note 1)	300mW
Differential Input Voltage	±15V
Common Mode Input Voltage (Note 2)	±15V
Voltage Between Offset Null and V^-	±0.5V
Operating Temperature Range	
NE531	0°C to +70°C
SE531	-55°C to +125°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Solder, 60 sec.)	300°C
Output Short Circuit Duration (Note 3)	Indefinite

NOTES:
1. Rating applies for case temperatures to 125 °C, derate linearly at 6.5mW/°C for ambient temperatures above +75°C
2. For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.
3. Short circuit may be to ground or either supply. Rating applies to +125°C case temperature or +75°C ambient temperature.

PIN CONFIGURATION

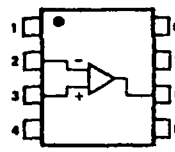
T PACKAGE
(Top View)



1. Offset Null
2. Inverting Input
3. Noninverting Input
4. V^-
5. Offset Null
6. Output
7. V^+
8. Freq. Comp.

ORDER PART NOS.
SE531T/NE531T

V PACKAGE

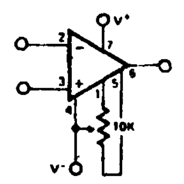


1. Offset Null
2. Inverting Input
3. Noninverting Input
4. V^-
5. Offset Null
6. Output
7. V^+
8. Freq. Comp.

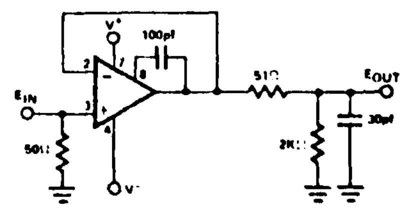
ORDER PART NO. NE531V

TEST CIRCUITS

OFFSET NULL CIRCUIT



TRANSIENT RESPONSE TEST CIRCUIT



GENERAL ELECTRICAL CHARACTERISTICS ($V_S = \pm 15V$, $T_A = 25°C$ Unless Otherwise Specified)

NE531

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Input Offset Voltage	$R_S \leq 10K\Omega$		2.0	6	mV
Input Offset Current			50	200	nA
Input Bias Current			0.4	1.5	μA
Input Resistance			20		MΩ
Input Voltage Range		±10			Volts
Common Mode Rejection Ratio	$R_S \leq 10K\Omega$	70	100		dB
Supply Voltage Rejection Ratio	$R_S \leq 10K\Omega$		10	150	μV/V
Large Signal Voltage Gain	$R_L \geq 2K\Omega$, $V_{OUT} = \pm 10V$	20,000	60,000		
Output Resistance			75		Ω
Supply Current			5.5	10	mA
Power Consumption			165	300	mW
Full Power Bandwidth			500		KHz
Settling Time, 1%	$A_V = +1$, $V_{IN} = \pm 10V$		1.5		μsec
Settling Time, .01%	$A_V = +1$, $V_{IN} = \pm 10V$		2.5		μsec
Large Signal Overshoot	$A_V = +1$, $V_{IN} = \pm 10V$		2		%
Small Signal Overshoot	$A_V = +1$, $V_{IN} = 400mV$		5		%
Small Signal Risetime	$A_V = +1$, $V_{IN} = 400mV$		300		nsec
The Following Apply for $0°C \leq T_A \leq +70°C$:					
Input Offset Voltage	$R_S \leq 10K\Omega$			7.5	mV
Input Offset Current	$T_A = +70°C$			200	nA
	$T_A = 0°C$			300	nA
Input Bias Current	$T_A = +70°C$			1.5	μA
	$T_A = 0°C$			2.0	μA
Large Signal Voltage Gain	$R_L \geq 2K\Omega$, $V_{OUT} = \pm 10V$	15,000			
Output Voltage Swing	$R_L \geq 2K\Omega$	±10	±13		Volts
Slew Rate	$A_V = 100$		35		V/μs
	$A_V = 10$		35		V/μs
	$A_V = 1$ (non-inverting)		30		V/μs
	$A_V = 1$ (inverting)		35		V/μs
Supply Current	$T_A = +70°C$		4.5	5.5	mA

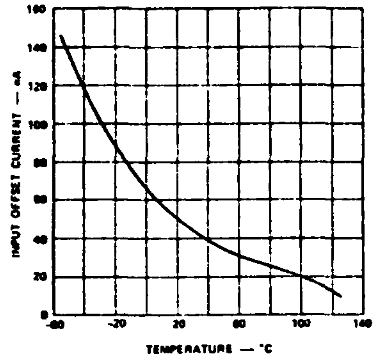
SE531

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Input Offset Voltage	$R_S \leq 10K\Omega$		2.0	5.0	mV
Input Offset Current			30	200	nA
Input Bias Current			300	500	nA
Input Resistance			20		MΩ
Input Voltage Range		±10			Volts
Large Signal Voltage Gain	$R_L \geq 2K\Omega$, $V_{OUT} = \pm 10V$	50,000	100,000		
Output Resistance			75		Ω
Supply Current			5.5	7.0	mA
Power Consumption			165	210	mW
Full Power Bandwidth			500		KHz
Settling Time, 1%	$A_V = +1$, $V_{IN} = \pm 10V$		1.5		μsec
Settling Time, .01%	$A_V = +1$, $V_{IN} = \pm 10V$		2.5		μsec
Large Signal Overshoot	$A_V = +1$, $V_{IN} = \pm 10V$		2		%
Small Signal Risetime	$A_V = +1$, $V_{IN} = 400mV$		300		nsec
Small Signal Overshoot	$A_V = +1$, $V_{IN} = 400mV$		5		%
Slew Rate	$A_V = 100$		35		V/μs
	$A_V = 10$		35		V/μs
	$A_V = 1$ (non-inverting)		30		V/μs
	$A_V = 1$ (inverting)		35		V/μs
The following apply for $-55°C \leq T_A \leq +125°C$:					
Input Offset Voltage	$R_S \leq 10K\Omega$			6	mV
Input Offset Current	$T_A = +125°C$			200	nA
	$T_A = -55°C$			500	nA
Input Bias Current	$T_A = +125°C$			500	nA
	$T_A = -55°C$			1.5	μA
Common Mode Rejection Ratio	$R_S \leq 10K\Omega$	70	90		dB
Supply Voltage Rejection Ratio	$R_S \leq 10K\Omega$		10	150	μV/V
Large Signal Voltage Gain	$R_L = 2K\Omega$, $V_{OUT} = \pm 10V$	25,000			
Output Voltage Swing	$R_L = 2K\Omega$	±10	±13		V
Supply Current	$T_A = +125°C$		4.5	5.5	mA

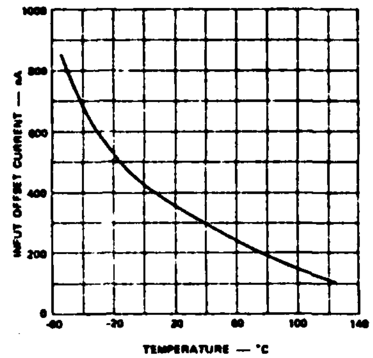
NOTES:
All AC parametric testing is performed using the conditions of the transient response test circuit, page 1.

TYPICAL PERFORMANCE CHARACTERISTICS (V_S = ±15V, T_A = +25°C unless otherwise noted)

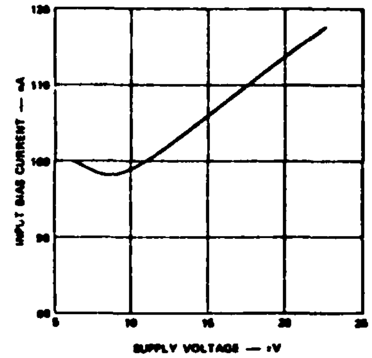
INPUT OFFSET CURRENT AS A FUNCTION OF AMBIENT TEMPERATURE



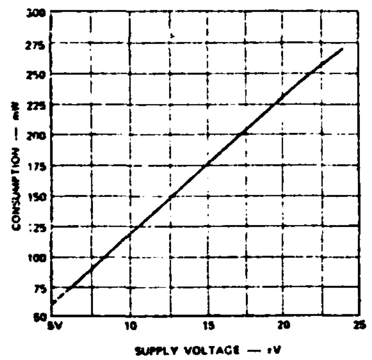
INPUT BIAS CURRENT AS A FUNCTION OF AMBIENT TEMPERATURE



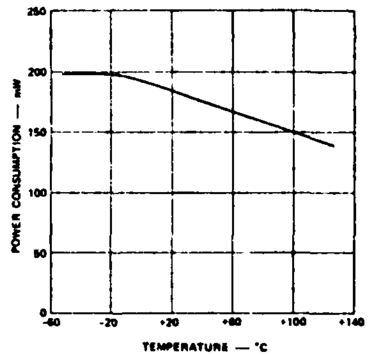
INPUT BIAS CURRENT AS A FUNCTION OF SUPPLY VOLTAGE



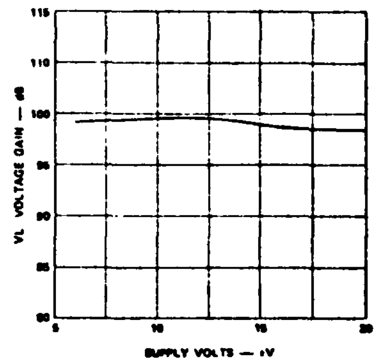
POWER CONSUMPTION AS A FUNCTION OF SUPPLY VOLTAGE



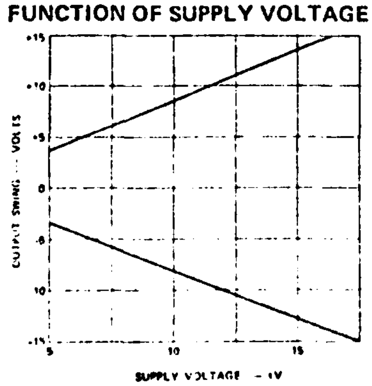
POWER CONSUMPTION AS A FUNCTION OF AMBIENT TEMPERATURE



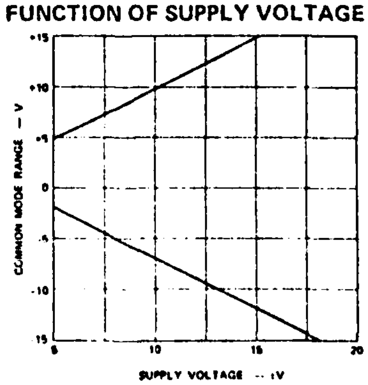
OPEN LOOP VOLTAGE GAIN AS A FUNCTION OF SUPPLY VOLTAGE



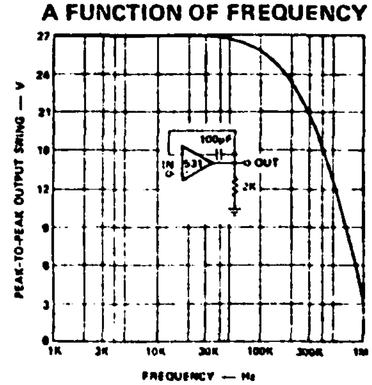
OUTPUT VOLTAGE SWING AS A FUNCTION OF SUPPLY VOLTAGE



INPUT VOLTAGE RANGE AS A FUNCTION OF SUPPLY VOLTAGE

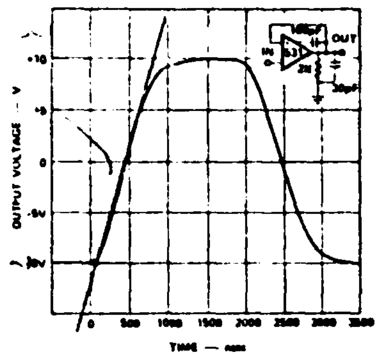


OUTPUT VOLTAGE SWING AS A FUNCTION OF FREQUENCY

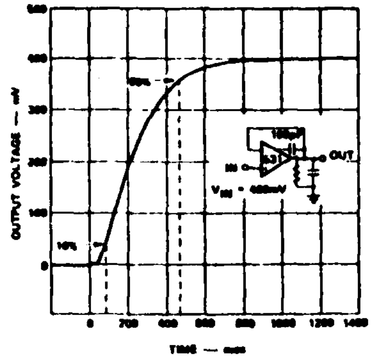


TYPICAL CHARACTERISTIC CURVES (Cont'd.)

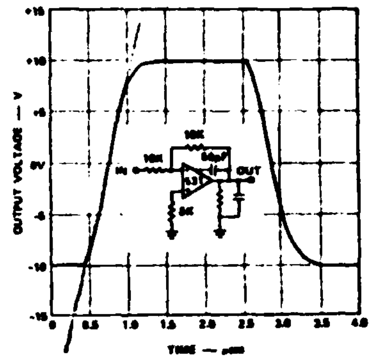
VOLTAGE FOLLOWER
LARGE SIGNAL RESPONSE



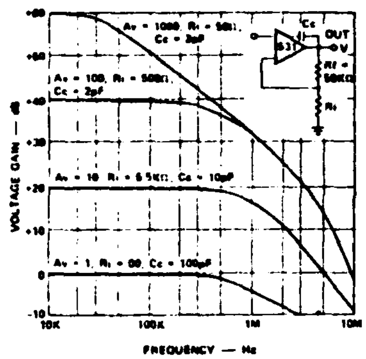
VOLTAGE FOLLOWER
TRANSIENT RESPONSE



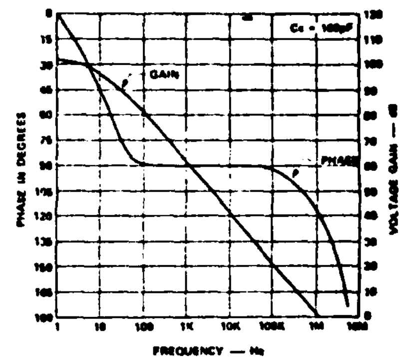
UNITY GAIN
INVERTING AMPLIFIER
LARGE SIGNAL RESPONSE



CLOSED LOOP NON-INVERTING VOLTAGE
GAIN AS A FUNCTION OF FREQUENCY

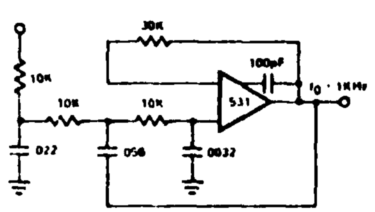


OPEN LOOP PHASE RESPONSE AND VOLTAGE
GAIN AS A FUNCTION OF FREQUENCY

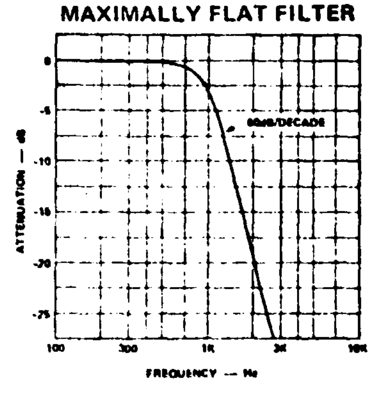


TYPICAL APPLICATIONS

3 POLE ACTIVE LOW PASS FILTER BUTTERWORTH MAXIMALLY FLAT RESPONSE*



RESPONSE OF 3-POLE ACTIVE
BUTTERWORTH
MAXIMALLY FLAT FILTER



*Reference – EDN Dec. 15, 1970
Simplify 3 Pole Active Filter Design
A. Paul Brokow

APPENDIX B

POWER SUPPLIES

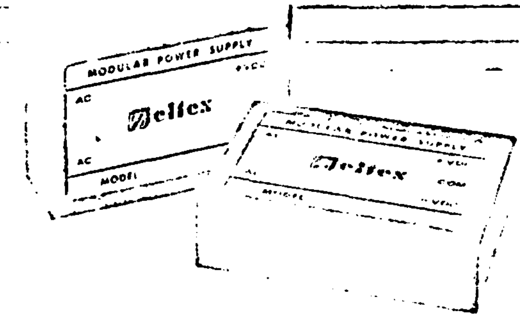
Power Supplies for Logic, Linear, Data Converters and Display Systems

- Most Flexible Line in the Industry — 48 models
- Three choices of Regulation
- Miniature and Sub-miniature packages
- Six standard Input Voltages — AC and DC
- Transformer Inputs and Frequency Converters
- Single, Double, and Triple ouputs
- 0.02% Line/Load Regulation — less than 1 mV of noise
- Lowest Prices (As low as $16)
- Coolest Operation — No derating for up to 71°C
- 115V-250V Primaries

GENERAL DESCRIPTION

The Zeltex T-Series and Z-Series Power Supply Modules offer the highest performance and broadest selection of power supplies available today. A complete line in terms of input voltage, output voltage, output current, regulation and physical size is available at the lowest prices in the industry. Output Power of up to 6 watts is available in the small, standard T-size case (7.5 cu. inches), or up to 4.5 watts in the sub-miniature Z-size case (1.4 cu. inches).

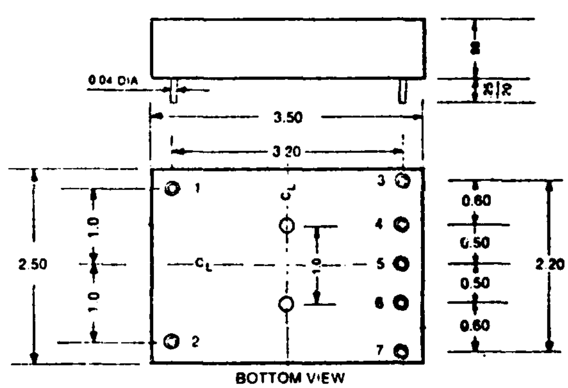
The T-series case is essentially an industry standard size and is compatible and interchangeable with most other competitive units. The Z-Series case is designed for use where small size is desired. These sub-miniature units are identical in size and compatible with the Zeltex line of converters (see ADC and DAC sections). The T-series uses a glass filled diallylphthalate case and "potted" with aluminum oxide filled epoxy (meeting MIL-M14 Type SDG-F Specifications). This construction allows higher heat conduction (and therefore a lower case temperature) and insures reliable operation in "tough" environmental conditions.



MODEL No. Z15AT200DP

Voltage: ±15
Output Current: 200 mA
Load Regulation: .02%
Line Regulation: .02%
Ripple (RMS) mV: 2.0
Input Voltage: 115 ±10VAC
50 to 450 HZ

Case Style T



T-Case Output Pin Functions

Output Voltage	Pin #	Supply Type
+15	3	Dual ±15
15	7	Dual ±15
Common	5	Dual ±15
+5	3	Single 5V
5	7	Single 5V
+15	3	Triple ±15 +5V
15	7	Triple ±15 +5V
Common	5	Triple ±15 +5V
+5	4	Triple ±15 +5V
5	6	Triple ±15 +5V

T-Case Input Pin Functions

115V ±10V AC 1 & 2
230V ±25V AC 1 & 2
100V to 250 VAC 1 & 2

Notes: T-Case

1. Use MC 27A socket
2. Mounting screw inserts are electronically floating (not connected to common)

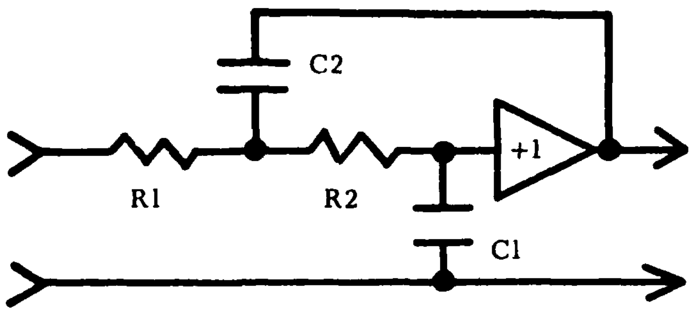
GENERAL SPECIFICATIONS

Applies to all power units — Typical at 25°C unless noted
Outputs are short circuit protected. (Precision and limited units)
Output impedance — 0.2 ohm at 10 kHz.
Input/Output isolation — 500 VDC
Input isolation — 50 Mohms

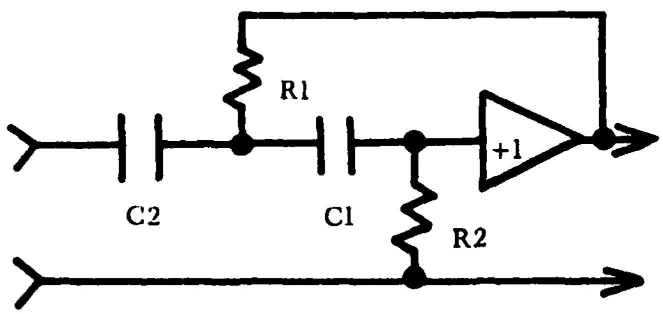
Operating Temperature Range −25° to +71°C.
Storage Temperature Range — −25° to +85°C
Relative Humidity — 90% non condensing.
Current Derating — none from −25° to +71°C.
Warm-up Time — 30 minutes.

APPENDIX C
HP/LP FILTER DESIGN

The one restriction placed on the filter design was that the same components should be used in both HP and LP configurations.



LOW PASS FILTER



HIGH PASS FILTER

The active filter circuit configurations shown above are noninverting voltage-controlled voltage source configurations. For each filter the break frequency

$$(1) \qquad Wn = \frac{1}{\sqrt{R1R2C1C2}} \quad . \quad *$$

The damping factor for the low pass case is given by *

$$(2) \qquad \delta_{LP} = 1/2\,(R1 + R2)\,C1Wn$$

and for the high pass case

$$(3) \qquad \delta_{HP} = 1/2\,(C1 + C2)\,R1Wn.$$

Equating the damping factors,

$$\delta_{LP} = \delta_{HP}$$

$$1/2\,(R1 + R2)\,C1Wn = 1/2\,(C1 + C2)\,R1Wn$$

$$\frac{R1 + R2}{R1} = \frac{C1 + C2}{C1}$$

$$(4) \qquad \frac{R2}{R1} = \frac{C2}{C1} = a$$

To solve for the constant, a, the damping factor δ_{LP} will be set to $1/\sqrt{2}$ for a maximally flat response.

$$(5) \qquad \delta_{LP} = 1/\sqrt{2} = \frac{1/2\,(C1 + C2)\,R1}{\sqrt{a^2\,R1^2 C2^2}} = \frac{(a + 1)}{2a}$$

Solving for "a" we have,

$$a = \frac{\sqrt{2}}{(2 - \sqrt{2})} = 2.41$$

* Ioannides, P. G., "Design Complex Active Filters With Few Equations" EDN, March 15, 1972, p. 53.

Design Example:

A HP/ LP filter is desired with a break frequency of 1000 Hz, C1 will arbitrarily be selected at 0. 015 MFD.

Solving for C2 we have,

$$(6) \qquad C2 = \frac{C1}{a} = \frac{.015}{2.41}\text{MFD} = .00625\ \text{MFD.}$$

The closest off-the-shelf capacitor value is 0. 0068 MFD. This will be used to calculate the resistor values. From equation (1) ,

$$(7) \qquad R1R2 = 1/Wn^2C1C2 = 25 \times 10^7\ \Omega^2$$

$$(8) \qquad \frac{R2}{R1} = 2.41$$

Combining (7) and (8) we have,

$$R1^2 = 104 \times 10^6 \qquad \text{thus, } R_1 = 10.2\ K\Omega$$

$$R2 = a\ R1 = 24.6\ K\Omega$$

This completes the filter design process.

APPENDIX D
BASIC COMPUTER DESIGN PROGRAM

```
LIST
10  PRINT " **** HP/LP BUTTERWORTH FILTER, 2 POLE, 8/72, S BURKE ****"
20  PRINT "SELECT C1, (ENTER IN MFD)"
30  INPUT C1
35  LET C1=C1*1.00000E-06
40  LET A=2.41
50  LET C2=C1/A
60  LET X=C2/1.00000E-06
70  PRINT "C2 =";X,"MFD"
75  PRINT "IS THE VALUE OF C2 OK ?, (1=YES, 0=NO)"
80  INPUT Y
90  IF Y >= 1 THEN 110
100  GOTO 20
110  PRINT "ENTER ACTUAL VALUE OF C2 USED IN FILTER, (ENTER IN MFD) "
120  INPUT C2
130  LET C2=C2*1.00000E-06
140  PRINT " ENTER BREAK FREQUENCY IN HZ"
150  INPUT F
160  REM  G=R1*R2
170  LET G=1/((6.28*F)^2*C1*C2)
180  LET R1=SQR(G/A)
190  LET R2=A*R1
200  PRINT "R1=";R1,"OHMS","R2=";R2,"OHMS"
210  PRINT
220  PRINT
230  PRINT "NEW FREQ ?, YES=1, NO=0"
240  INPUT Z
250  IF Z >= 1 THEN 270
260  GOTO 280
270  GOTO 140
280  PRINT
290  PRINT
999  END

READY




RUN
 **** HP/LP BUTTERWORTH FILTER, 2 POLE, 8/72, S BURKE ****
SELECT C1, (ENTER IN MFD)
?1.5
C2 = .622407                  MFD
IS THE VALUE OF C2 OK ?, (1=YES, 0=NO)
?1
ENTER ACTUAL VALUE OF C2 USED IN FILTER, (ENTER IN MFD)
?.[illegible]
 ENTER BREAK FREQUENCY IN HZ
?[illegible]
R1= 101.562    OHMS             R2= 244.765    OHMS


NEW FREQ ?, YES=1, NO=0
?0



READY
```

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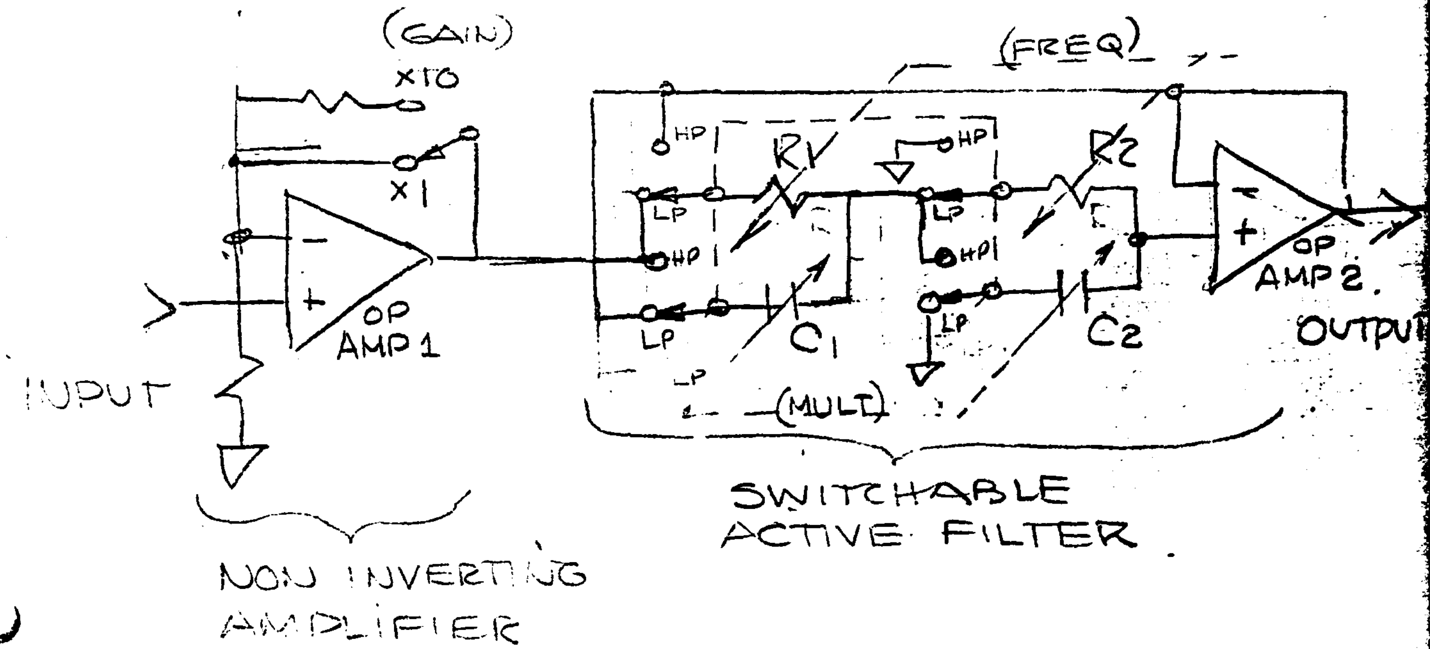
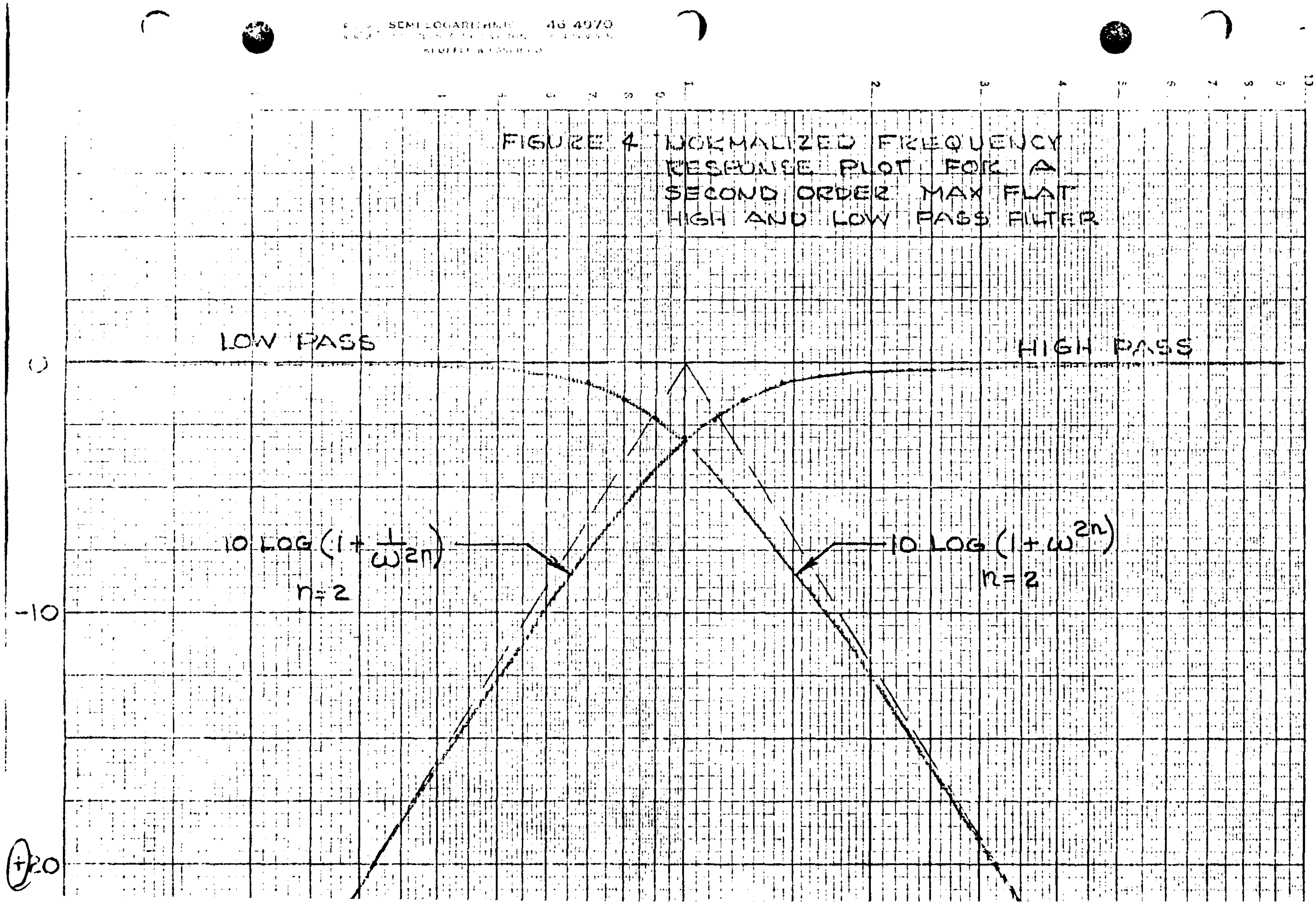
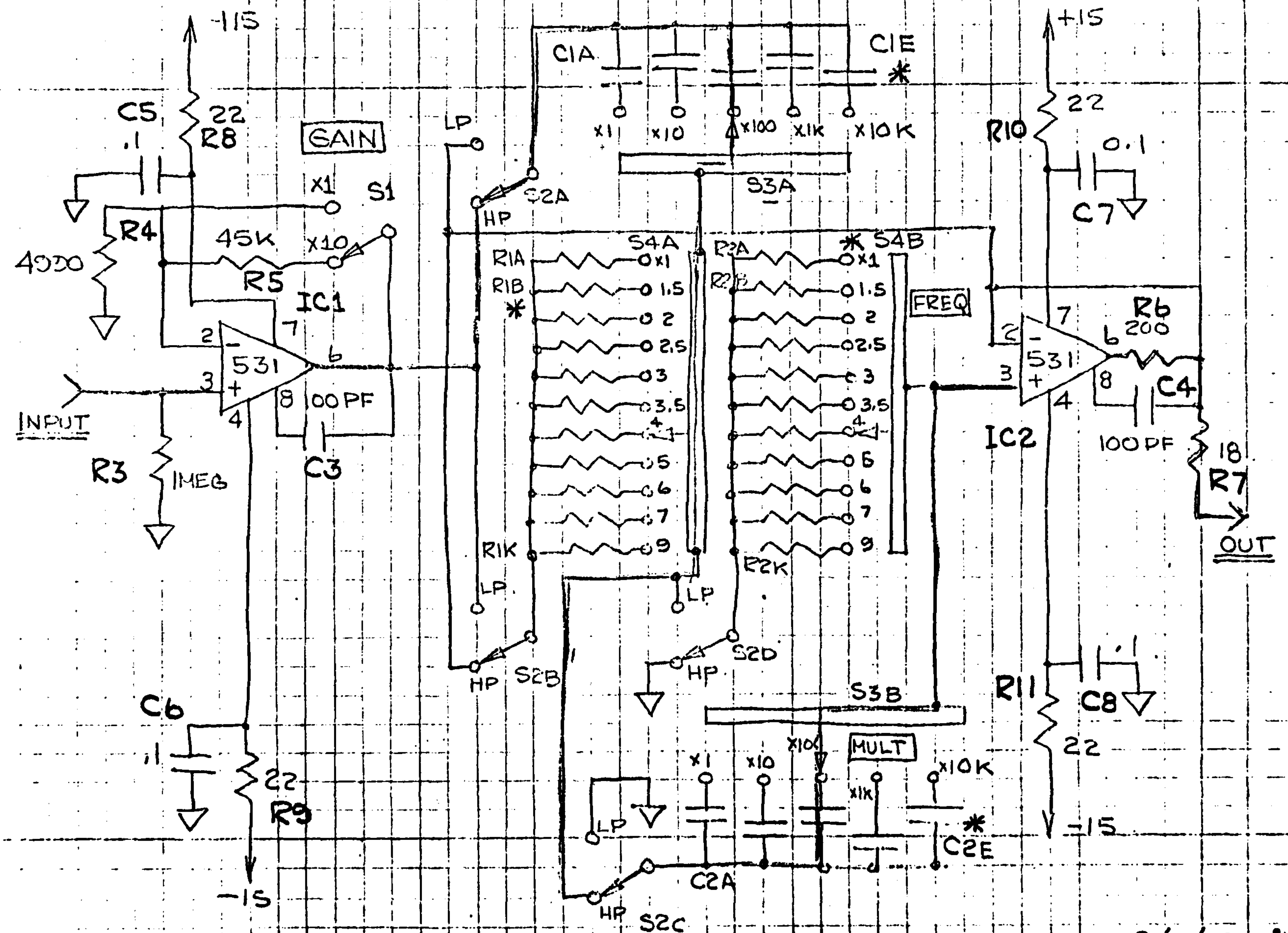


FIGURE 3 HP/LP FILTER SIMPLIFIED SCHEMATIC



SEMI-LOGARITHMIC 46 4970
FIGURE 4 NORMALIZED FREQUENCY RESPONSE PLOT FOR A SECOND ORDER MAX FLAT HIGH AND LOW PASS FILTER
LOW PASS
HIGH PASS
$10 \log \left(1 + \frac{1}{\omega^{2n}}\right)$
$n = 2$
$10 \log \left(1 + \omega^{2n}\right)$
$n = 2$
0
-10
-20
1
2
3
4
5
6
7
8
9
10



* SEE PARTS LIST FOR COMPONENT VALUES

LOW PASS / HIGH PASS FILTER

9/8/72

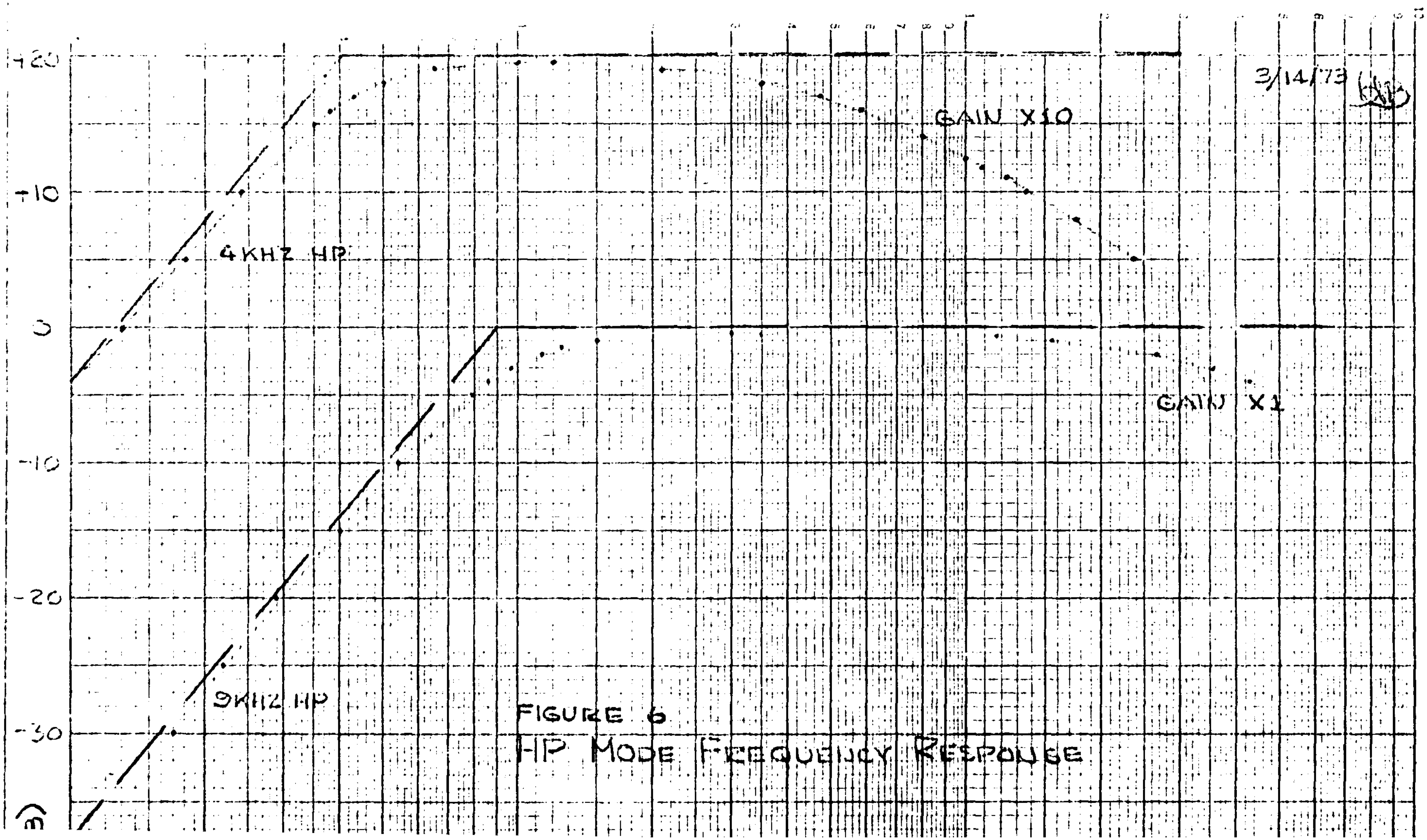


FIGURE 6
HP MODE FREQUENCY RESPONSE